Sub-threshold J/ψ Photoproduction

(A new proposal to JLab PAC 23)

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Abstract

We propose to measure the cross section for J/ψ photoproduction from beryllium using the SOS and HMS spectrometers in Hall C to detect lepton pairs from charmonium decay. We use an untagged bremsstrahlung beam by passing a high current (60 μA) 6 GeV electron beam through the thick Be target. We request seven days for this exploratory measurement, with the running time divided among two spectrometer settings to scan the t-dependence of the cross section. We expect to observe somewhere between 1 and 1000 events at each kinematic setting, with backgrounds at or below the level of 1 count. The kinematics are sub-threshold to production from a free proton, so the experiment will probe rare short distance configurations in the nucleus, and will be sensitive to higher twist effects (such as three-gluon exchange), intrinsic charm contributions, and possible multi-quark resonances involving charmed quarks.

1 Introduction

One of the main goals of nuclear physics is to understand to what extent a nucleus is differs from a loosely bound system of quasi-independent nucleons. When nucleons are very close spatially, corresponding to rare high momentum components of the single particle wave function, many interesting and potentially exotic configurations can arise. One way to look for such configurations is with reactions that are significantly sub-threshold to production from a free nucleon. Of all such reactions, photoproduction of charmonium is one of the cleanest, because the charm quark content of a nucleon is very small compared to the light quarks. In light meson photoproduction, the quark content of the mesons can originate in the nuclear target, while in the case of charmonium photoproduction, the quark-interchange mechanism is essentially absent, and the reaction must proceed via gluon exchange in order for color to be conserved. In addition, the heavy mass of the charm quark (about 1.5 GeV) ensures a hard scale to the problem, making it more tractable in QCD.

There is currently very little known about sub-threshold J/ψ photoproduction, either theoretically or experimentally. Theoretical estimates that have been made to date show several order-of-magnitude variations. The estimates of the rates expected both with "ordinary" Fermi-smearing assumptions, as well as with more interesting effects, will certainly be refined in the next years, in particular in anticipation of the results of this proposed experiment. Improved data in the above-threshold region from SLAC and eventually JLab at 12 GeV will help reduce the uncertainties in the free-nucleon cross sections. On the experimental front, very preliminary analysis of lepton-pair photoproduction data from CLAS shows one possible event candidate in the J/ψ mass region, which gives a hint at the order-of-magnitude of the sub-threshold cross section.

We propose to increase the sensitivity of the CLAS data by more than two orders of magnitude in an exploratory investigation of sub-threshold J/ψ photoproduction using the two spectrometers in Hall C. Using two spectrometer settings, we can roughly map out the magnitude and t-dependence of the cross section, and perhaps set the stage for more detailed investigations. By using a pair of high-resolution spectrometers to detect lepton pairs from J/ψ decays, we are confident that a significant J/ψ signal will be seen above backgrounds.

1.1 Relation to Quark-Gluon plasma Search

J/ψ suppression in heavy ion collisions has been regarded as one of the more interpretable of the many signals that might indicate the onset of a quark-gluon plasma state. Unfortunately, there is presently sufficient uncertainty in the production and propagation mechanisms that the J/ψ suppression data from CERN SPS can potentially be explained by conventional nuclear physics models [1]. Better understanding of how charmonium is procured, and how it interacts with nucleons is needed, to understand if the heavy ion data from CERN and RHIC indicate the onset of a new state of matter, or not. The present proposal is designed to address the question of how charmonium is produced in kinematics where the probability that two or more nucleons are in close proximity is enhanced, as may be relevant to heavy ion collisions.

1.2 The J/ψ -nucleon cross section

In order to get a better handle on the other part of the heavy ion problem, the effective J/ψ -nucleon cross section, an experiment has been approved at SLAC [2] to measure the A-dependence of J/ψ and ψ' photoproduction with photon energies from 15 to 35 GeV. The use of a photon probe simplifies the interpretation, relative to previous experiments using hadroproduction, because initial state interactions are minimized. Systematic and statistical errors will be greatly reduced compared to a previous SLAC experiment [3]. Of particular importance will be the addition of the ψ' state, which can be used to distinguish between geometric and hard scattering models of charmonium-nucleon interactions. There are plans [4] at JLab to extend these measurements on nuclei closer to the 8.2 GeV free nucleon threshold ,where the formation length is well within even the lightest nuclei. Data on a free nucleon are also planned to augment the relatively meager threshold data from Cornell [5] and SLAC [6], to help pin down the dominant production mechanisms. The E160 experiment will also probably be able to improve on the Cornell data, in a much closer time frame, using a LiD target and photon energies from 10 to 15 GeV.

1.3 Sub-threshold photoproduction

The goal of the present proposal is to study the production mechanisms in the extreme conditions of high density (short distance scales) that may be relevant in heavy ion collisions. These conditions are ensured by using a photon beam energy well below photoproduction threshold on a free nucleon. This study is complementary to the studies on nuclei at higher energies, which are more focused on the J/ψ -nucleon interaction.

In the single nucleon picture, nucleon Fermi momentum must be pointing anti-parallel to the photon direction for the invariant mass of the photon-nucleon system s to be above the threshold value of $(m+M_j)^2 = 16.3$ GeV^2, where m is the nucleon mass and M_j is the J/ψ mass. The minimum Fermi momentum increases as the photon energy decreases, as shown in Fig. 1a. It is generally thought that the region where multi-nucleon correlations, hidden color configurations, and other short-range effects play a significant role is for momenta beyond 350 MeV. This corresponds to a photon of energy of 6 GeV, well-matched to the present capabilities of JLab. At lower energies, count rates become prohibitively low, while at higher energies, the Fermi-surface contributes most of the cross section, and essentially the reaction processes on a nearly free nucleon are probed. This important part of the program can best be done with photon energies of 8 to 11 GeV in the future JLab upgrade [4].

The high Fermi momentum region is where multi-nucleon correlations are known to be important, and where high density fluctuations could significantly enhance the yield compared to a simple Fermi-smearing model. In the hard-scattering picture [7], this could correspond to strong contributions of higher twist 3-gluon exchange, compared to the minimal 2-gluon exchange needed to ensure the J/ψ color singlet final state. The influence of intrinsic charm contributions, or hidden color contributions, could potentially increase the cross section by an order of magnitude above the expectation from single quasi-free Fermi-smearing (see Fig. 5 of Ref. [7]). Another possibility to enhance the sub-threshold cross section is a diagram in which two gluons are exchanged to two different nucleons. This type of process could become important in the sub-threshold region, because each of the gluons could have a much lower momentum fraction than if the pair of gluons comes from a single nucleon.

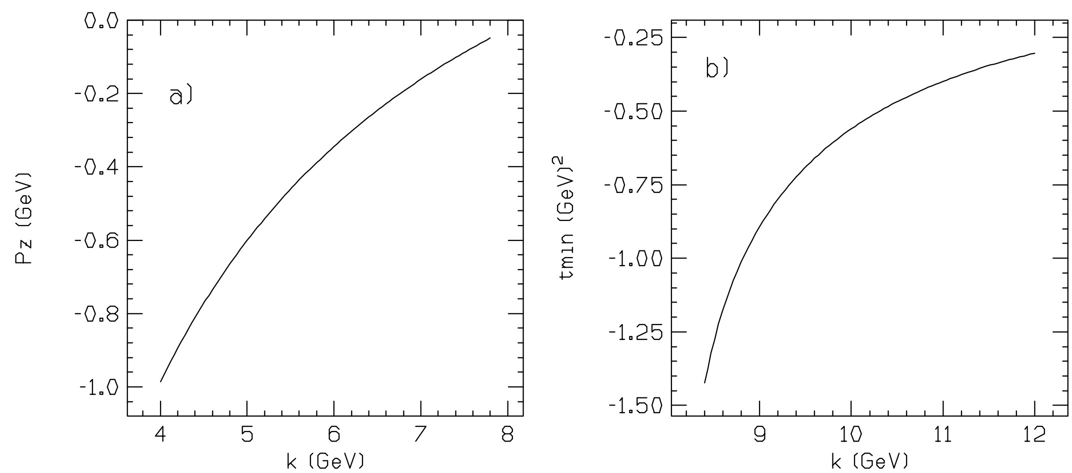

Figure 1: a) The minimum z-component of single nucleon momentum (where positive z is along the photon axis) needed for J/ψ photoproduction from a nucleus, as a function of photon energy. b) t_{min} versus photon energy for photoproduction from a free nucleon.

1.4 Relation to sub-threshold hadroproduction

In pA collisions, it has been observed that anti-protons and kaons are produced on nuclear targets at substantially lower energies than is kinematically possible on free nucleons [8]. Scattering on a single nucleon in the nucleus would at these energies require a Fermi momentum in the vicinity of 800 MeV. While the pA data can be fit assuming such high Fermi momenta, this assumption leads to an underestimate of sub-threshold production in AA collisions by about three orders of magnitude [9].

There are at least two qualitatively different scenarios for the observed sub-threshold production of anti-protons [10]. One scenario is that the projectile strikes a local "hot spot" with a high energy density in the nucleus. The effective mass of the scatterer is high, lowering the kinematic threshold. Alternatively the momentum required to create the anti-proton is not transferred locally, but picked up in an extended longitudinal region. Establishing either scenario would teach us something qualitatively new about rare, highly excited modes of the nucleus.

Sub-threshold photoproduction can help to identify the correct mechanism, because the $c\bar{c}$ component of the photon is almost point-like at the charm threshold and below. Effects due to the shrinking effective size of a hadron probe near threshold are eliminated. The $c\bar{c}$ pair is created locally, within a proper time $\tau \simeq 1/m_c$. The extended acceleration scenario is thus not effective for charm photoproduction. If significant sub-threshold charm photoproduction occurs (beyond what can be ascribed to standard Fermi motion) this selects the hot spot scenario.

2 Existing data and models near threshold

There are no published data on sub-threshold photoproduction, but it is useful to review the existing data just above threshold on a free nucleon, as this provides the baseline for sub-threshold predictions based on simple Fermi-smearing models, as described below. The existing data below 20 GeV come from Cornell [5] using 9.3 to 11.8 GeV photons, and from SLAC [6] from 13 to 21 GeV. These experiments detected lepton pairs from the J/ψ decay to provide relatively background-free measurements. Additional unpublished data from SLAC [11] detected only a single lepton, leading to relatively large background subtractions.

The experiments typically parameterize the data according to $d\sigma/dt = Ae^{bt}$. Values of b from the threshold experiments as well as from high energy experiments are shown in Fig. 2. What is remarkable is that, while b has values of about 6 GeV^{-2} at high energy, which are characteristic of diffractive processes, the values drop rapidly near threshold, with Cornell [5] quoting a value of only 1.25 ± 0.2 GeV^{-2} near 11 GeV photon energy. [As pointed out by [12], the actual slope of the data seems to be more like 1.5 GeV^{-2}, still quite small]. The Cornell value is more than a factor of two below the SLAC value of $b = 2.9 \pm 0.3$ GeV^{-2} at 19 GeV. As the curves in the figure show, it is difficult to reconcile the two experiments with a smooth fit, assuming the exponential form corresponds to an effective form factor. One way to resolve this is to assume that $d\sigma/dt$ scales as a dipole form factor squared of the form $(1 - t/m_0^2)^{-4}$ [12]. A reasonably good fit to all data up to photon energies of 100 GeV can be found with $m_0^2 \approx 1$ GeV^2. Since each experiment measured over a limited range of t, and $-t_{min}$ increases near threshold, a natural explanation for the variation of b with photon energy can be found. We find a reasonable fit to the low energy data is given by $d\sigma/dt = 2.5/(1-t)^4$ nb/GeV^2, where t is in units of GeV^2.

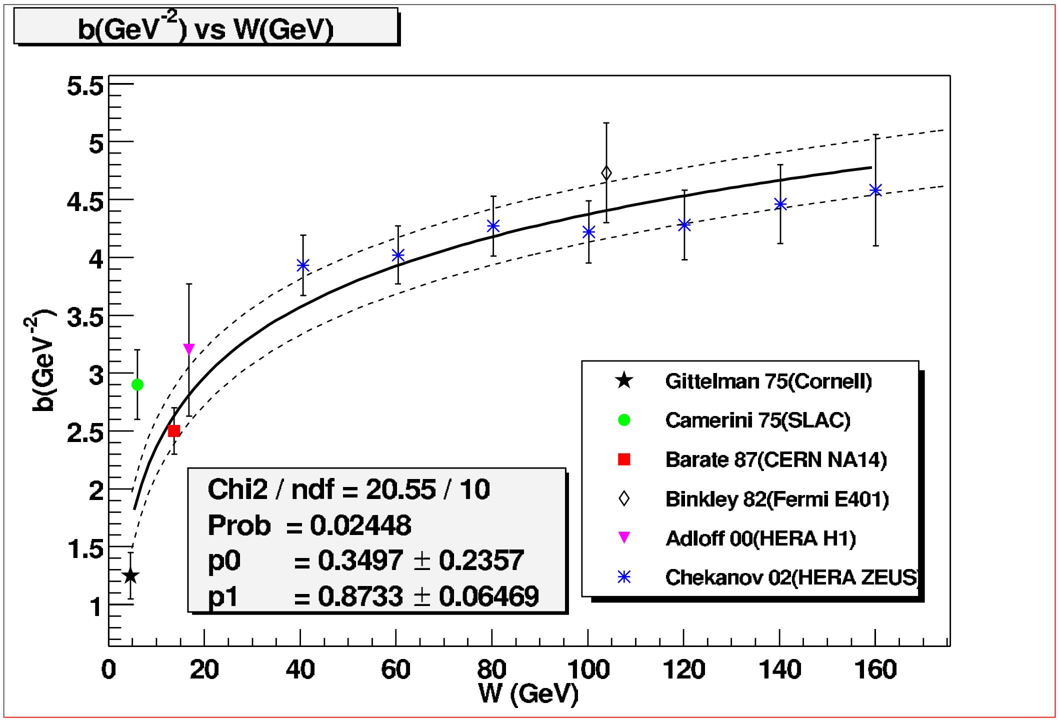

Figure 2: Slope parameter b from fits of the form Ae^{bt} to various J/ψ photoproduction experiments, as a function of $W = \sqrt{s}$.

The total cross sections are shown in Fig. 3. The total cross sections drop very rapidly towards threshold, but then both the Cornell and SLAC single arm data appear to flatten out and become almost independent of energy below 12 GeV. The two curves are from [7], corresponding to all of the cross section at 12 GeV being described by 2-gluon or higher twist 3-gluon exchange, assuming that the effective 2-gluon and 3-gluon form factors are both given by $F^2 = e^{1.13t}$. A transition from the 2-gluon exchange process to the higher-twist 3-gluon process near threshold provides one possible explanation of the flattening of the cross section near threshold. The 3-gluon process has a much weaker s dependence, because the momentum transfer is shared among more gluons, and the number of spectators is reduced, which enhances the cross section by a factor of $(1-x)^{-2}$, where, in the definition of [7], the momentum fraction $x = (s_{th} - m^2)/(s - m^2)$ is close to unity for threshold photoproduction. As shown in [12], the almost flat cross section near threshold can also be explained 2-gluon exchange, because in their formalism x has a maximum value of about 0.8, so factor such as $(1-x)^2$ does not cause a large threshold suppression.

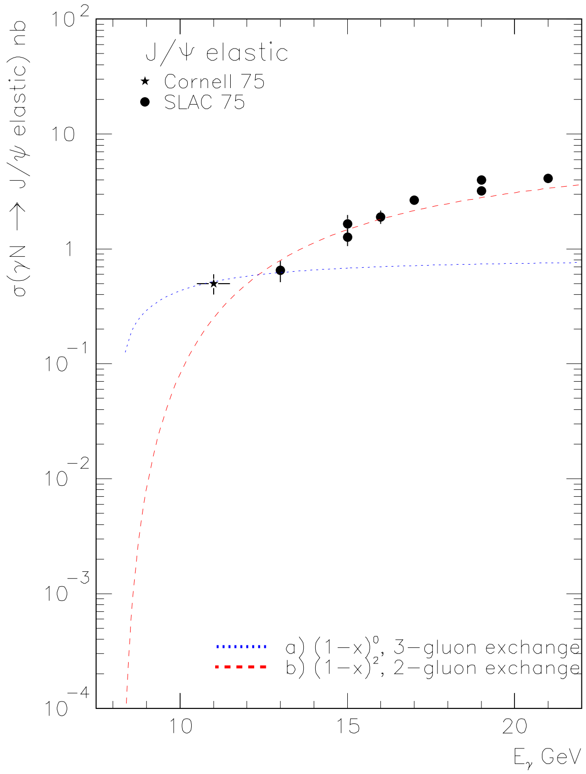

Figure 3: Total cross section for exclusive J/ψ photoproduction from a proton as a function of photon energy. The steeper (flatter) curve is the simple 2-gluon (3-gluon) model of [7], normalized to the data at 12 GeV.

3 Sub-threshold cross section estimates

An estimate of the sub-threshold cross sections for carbon has recently been published [13]. The authors assume dominance of the pQCD photon-gluon process. Their estimates give about 2 fb/nucleon for carbon for 6 GeV photons. However, their free proton cross sections are about a factor of five below the Cornell data [5], so it seems reasonable to apply a normalization factor (usually called K factor) of five, to obtain about 10 fb/nucleon. The prediction is more than four orders of magnitude below the free nucleon total cross section of about 0.5 nb for $k = 11$ GeV, where k is the photon energy. In this picture, this comes about because the Bjorken x values at which the gluon distribution function are evaluated become very large as the photon energy is decreased, and the gluon distribution is assumed to fall rapidly at large x. This estimate is probably a lower bound on the cross section for carbon, because both the t and s-dependence of the assumed elementary cross section are much steeper than indicated by the Cornell data. In any case, it seems unlikely that the hard, perturbative QCD photon-gluon fusion diagram would dominate at such low energies.

To obtain more realistic estimates, we have performed our own calculations, based on fits to existing data and assuming the quasi-free mechanism dominates, using the convolution integral [7]

$$d\sigma = \int d\sigma_0/dt(s,t) n(p) d^3p dt \qquad (1)$$

where the integral is limited to the kinematically allowed region, $d\sigma_0/dt(s,t)$ is the cross section for a free nucleon, and the nucleon distribution function $n(p)$ [14] is normalized such that $\int n(p)d^3p = 1$. We performed another integral over the photon energy range $5.3 < k < 6$ GeV, weighted by the bremsstrahlung distribution $1/k$. As a reasonable match to both the Cornell data and the 3-gluon description of [7], we use the Cornell fit $d\sigma_0/dt = 1.01e^{1.25t}$ nb/GeV^2. Since $-t_{min}$ increases close to threshold as shown Fig. 1b, the total cross section decreases by only a factor of two between 12 and 9 GeV, dropping another factor of five at the threshold energy of 8.2 GeV. In evaluating the cross section, we assumed that the photon interacted with a nucleon with total energy m (it's rest mass) and momentum $\vec{p}$, evaluating s and t ignoring the spectator nucleons. We take the heavy target limit, where the kinetic energy E_r of the recoiling system is small, and therefore assume $n(p,E)$ is independent of E_r. For a 6 GeV endpoint energy, we find a cross section of about 2 pb/nucleon. This corresponds to a roughly 1% probability of finding a nucleon in Be with enough Fermi momentum anti-parallel to the photon direction so that s of the photon-nucleon system is above threshold. We also investigated the effect of reducing the total energy of the struck nucleon by a factor $p^2/2M_s$, where M_s is the spectator mass. For $M_s = 3m$, corresponding to hitting a nucleon in a four-nucleon cluster, we find the total cross section is reduced by a factor of two, due to the higher Fermi momenta required to be above threshold.

As can be seen in Fig. 4a, most of the cross section comes from Fermi momenta in the range $0.4 < p < 1$ GeV, as desired to enhance the effects of short range effects. The $-t$ distribution peaks around 1.5 GeV^2, with a minimum value of about 0.8 GeV^2. Fig. 4b shows the kinematics of the produced J/ψ particles. The typical momentum is 4 to 5 GeV, while the typical angle is less than 5 degrees. The primary spectrometer setting that we have selected (see below) allows most of the momentum range to be covered, but selects the angles close to zero degrees (crosses in Fig. 4b).

We also calculated the cross section using the dipole form factor of [12]. With this form, the Cornell data can be fit as $d\sigma/dt = 2.5/(1-t)^4$ nb/GeV^2. We obtain about 0.5 pb/nucleon for the 6 GeV endpoint energy, a factor of four lower than using the exponential form factor.

As mentioned above, the effects of hidden color configurations, intrinsic charm contributions, and other short-distance effects could enhance the cross section by perhaps a factor of 10 [7]. Thus we can expect a maximum cross section of order 20 pb/nucleon for a 6 GeV electron beam.

3.1 Coherent contributions

Coherent diffractive photoproduction off Be nuclei occurs at very small values of $|t|$, with the differential cross section proportional to $\exp(-b|t|)$. Values of b around 30-40 have been reported from several photoproduction experiments on beryllium [15, 16]. High energy J/ψ

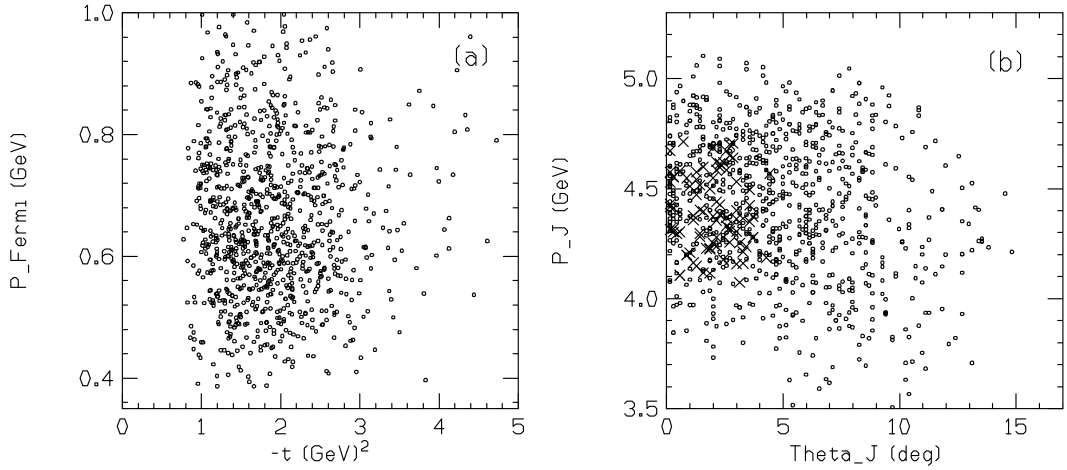

Figure 4: Using the quasi-free smearing model described in the text, the distribution of a) Fermi momentum versus $-t$; and b) J/ψ momentum versus angle in the lab system for a sample of all produced particles (circles), and detected particles (crosses).

photoproduction experiments, with sufficient resolution in t, are able to resolve the forward coherent peak, while there is no need for coherent corrections in low energy experiments due to the relatively large value of $|t_{min}|$. The SLAC experiment [6] demonstrated this by showing no difference in the cross section per nucleon from measurements on H_2 and D_2 at 19 GeV. Additionally, the Cornell measurement (see Fig. 2 in [5]) saw no coherent enhancement at their lowest values of t. Coherent production of J/ψ mesons with 6 GeV photons on Be has a $|t_{min}|$ of about 0.8 GeV, hence the contribution will be negligible.

4 Experimental Plan

4.1 Choice of equipment and Hall

Considering the extremely small cross sections involved, a clear and unambiguous signal is needed with very small backgrounds, for an exploratory experiment such as this one. The best way to do this is to detect the J/ψ decays to lepton pairs (6% B.R. for each of e^+e^- and $\mu^+\mu^-$) with two magnetic spectrometers. Assuming existing spectrometers, we find a slightly higher figure of merit for the Hall C spectrometers, compared to the two Hall A spectrometers (which have a better match in ϕ acceptance, but smaller momentum acceptance). The figure of merit for Hall B is much lower, in spite of the large acceptance of CLAS. This is because there is a high degree of correlation between the two leptons from J/ψ decays, and the J/ψ 's are produced at angles close to zero degrees. This favors the use of co-planar spectrometers. If the rates turn out to be sufficiently large, a future experiment may be able to use a pair of large solid angle lead glass arrays, as was done in the Cornell experiment [5]. The results of the present experiment will be essential to plan such a configuration.

4.2 Spectrometer settings

We optimized the spectrometer settings using a simple Monte Carlo simulation of the decays of J/ψ particles as produced by the quasi-free Fermi smearing model described in the previous section. We assumed s-channel helicity conservation in the decays, which favors asymmetric decays according to $1 + cos^2(\theta_{cm})$. Assuming the quasi-free smearing model, the distribution of all leptons for photons between 5.3 and 6 GeV is shown in Fig. 5a. The highest coincidence rates were found for the maximum SOS central momentum of 1.78 GeV, set at an angle of 52.5 degrees. The corresponding HMS settings are 3.6 GeV and 23 degrees. Fig. 5b shows the acceptances in (p, θ) space of each spectrometer. The crosses correspond the partners of leptons detected in the SOS, and the circles to those detected in the HMS. Note that the transverse momentum of each spectrometer is centered at 1.4 GeV (a bit below $M_{J/\psi}/2 = 1.55$ GeV), which is characteristic of decays slightly off of 90° in the center of mass.

The above setting is optimized for $1 < -t < 2$ GeV^2, where the quasi-free model predicts the most events. If contributions beyond the quasi-free mechanism are important, they are likely to peak at larger values of $-t$, corresponding to lower momenta for the J/ψ particles. We therefore propose to run with a second setting centered around $-t = 4$ GeV^2, corresponding to J/ψ momenta centered around 3.4 GeV. We find the highest rates by keeping the SOS momentum fixed at 1.78 GeV, and increasing the angle to 56 degrees. The corresponding HMS settings are 2.82 GeV and 31.5 degrees.

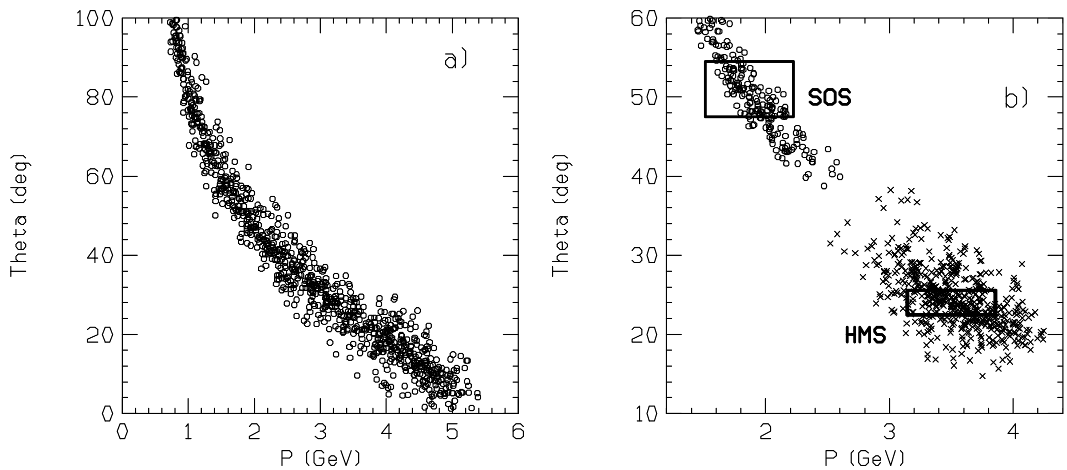

Figure 5: Momentum/angle distribution of lepton pairs from J/ψ decays using the simple convolution model described in the text, for $E = 6$ GeV. The samples contain equal mixtures of electron and muon pairs. a) All generated events. b) The acceptance of the SOS and HMS spectrometers for the high J/ψ momentum setting. The circles are the partners of the events detected in the HMS, while the crosses are the converse for the SOS spectrometer.

5 Detectors

The normal Hall C spectrometer setups have excellent electron/positron identification capabilities. Separating muons from pions is more problematic. In the case of the HMS spectrometer, we will set the pion threshold in the gas Cherenkov counter to be just below the maximum accepted momentum (i.e. about 8% above the central momentum). The threshold for muons will be 25% lower than for pions, and therefore 17% below the central momentum of the spectrometer (which has a nominal momentum acceptance of $\pm10\%$). Assuming 10 photo-electrons (PE) for fully relativistic particles (such as electrons), the muons will produce on average 2 PE to 4 PE over the spectrometer acceptance. With a threshold of 1 PE, the efficiency will range from 85% to 98%.

Additional muon identification will be provided by requiring minimum ionizing pulse heights in each of the four layers of the lead glass counters. In the SOS spectrometer, we would like to replace the fourth layer (which doesn't add much information for electron identification), with a lead wall to increase the probability of a hadronic shower from a pion. We plan to place a set of large scintillator detectors behind each lead glass array, and again look for a minimum ionizing signal from muons. Since hadrons interact strongly with matter, there is a high probability the a hadron will have an interaction in the lead glass counter or the lead in front of the scintillator panels, producing secondary particles. and thus producing larger pulse heights in the detectors. We will investigate the pion/muon separation effectiveness in both spectrometers with Monte Carlo studies and data from Hall C. As discussed below, our requirements on pion mis-identification in the lead glass and scintillators are not very strict: we can readily afford as high a 20% mis-identification probability.

5.1 Target, Radiator, Beam Current, Beam Energy

We propose to use a 6.3 gm/cm^2-thick Be target, corresponding to 10% r.l. Assuming a density of 1.848 gm/cm^2, the length will be 3.4 cm, well within the SOS acceptance. The effective photon flux is 8%, considering that on average half of the real photons produced in the target are usable, plus an effective 3% from small-angle electroproduction. No radiator will be used in front of the target. Given the limit of about 10% total radiation length in the Hall, we find it is optimal to use a thick target with no extra radiator up-beam of the target.

We propose to use the maximum beam current possible given the radiation safety limits. It may be useful to add some local shielding close to the target to allow the highest possible luminosity. Preliminary design work has already been done to add a lead lining to the inner and/or outer surfaces of the scattering chamber. This would benefit other experiments similar to ours, such as the $x > 1$ experiment. For the purposes of this proposal, we assume a current of 60 μA is possible. We propose to run at the highest possible beam energy (6 GeV) to maximize the counting rates.

An important consideration is the Be target width must be as small as possible, to minimize the number of π^0 photons that convert to positrons as they leave the target. We therefore propose to use a target width of only ± 2 mm.

5.2 True Count Rates

The true count rate is hard to predict, but we can estimate lower and upper end of the range. The lower end of the range comes from the photon-gluon fusion calculation of Braun and Vlahovic [13]. Folding the prediction (see above) with our luminosity and acceptance conditions leads to about 1 event detected in both spectrometers in four days of running. More realistic estimates probably comes using the Fermi-smearing model described above. With the exponential form factor, we predict about 100 counts for 4 days of running at the high momentum setting, and about 10 counts at the low momentum setting in 3 days. If we instead use the dipole form factor fit, the predicted rates drop by about a factor of four. If intrinsic charm or rare high density configurations are important, it is conceivable that higher rates might be possible, especially at the low momentum setting. However, 100 counts in the present proposal setup would correspond very roughly to about 0.2 counts in the pre-preliminary EG1 data from Hall B taken with 5.6/5.7 GeV electrons, shown in Fig. 6. Since there is at most one count visible near the J/ψ mass in this spectrum (within the EG1 resolution), we can estimate that of order 1000 counts is a reasonable upper limit for each kinematic setting.

We conclude that a total of seven days of running is sufficient to distinguish between the various models, which give over three order of magnitude difference in rates, and quite different ratios of counts in the low and high momentum settings.

5.3 Singles Rates

Assuming that the HMS is set for positive polarity (to minimize accidental coincidences), then we calculate rates of 100 Hz positrons and 1 kHz pions in the HMS, and 110 Hz electrons and 1 kHz pions in the SOS. The rates are similar at both kinematic settings, because the transverse momentum is kept constant at about 1.4 GeV. The rates in the SOS vary enormously across the large momentum acceptance: the above is a rough average. Dead time and pile-up will be negligible in the detectors at these low rates.

5.4 Accidental Rates

Based on the above singles rates and a time window of 2 nsec, we expect about 1 count per day of electron/positron accidental coincidences, spread over an invariant mass range of $2.6 < M_{ee} < 3.3$ GeV. With momentum resolution of 10^{-3} in each spectrometer, and an opening angle resolution of 2 mr, we expect a resolution of 6 MeV on M_{ee} for true J/ψ events. Allowing $\pm 3\sigma$, and an additional factor of five by requiring the reconstructed target positions to be in agreement within 5 mm, we therefore expect 0.01 accidental electron/positron coincidences per day, which can be considered to be negligible.

The rate of muon accidentals will likely be lower than for electrons, because the muon rate is dominated by pions that decay in flight, or are mis-identified in the detectors. We estimate that less than 20% of pions will be identified as muons in the SOS, with less than 2% in the HMS due to the higher momentum of the pions, and the additional rejection from requiring a signal in the Cherenkov counter. Since the pion rates are 10 times higher than the electron or positron rates in each spectrometer, the net result is a prediction of 0.005 muon accidental coincidences per day in the $M_{\mu\mu}$ region of interest.

5.5 Backgrounds

One source of background is due to electrons that scatter and produce a π^0, and one of the photons converts in the target to a positron with the right kinematics (or there is a Dalitz decay). The other possibility is a kaon which decays to a positron. Both of these are extremely rare for our kinematics, but difficult to model accurately. Therefore, we have used data from the EG1b experiment in Hall B. This experiment used targets of NH3 or ND3 with a little over 1 gm/cm^2 thickness, and beam energies of 5.6 and 5.7 GeV. The electron/positron acceptance was from about 10 to 45 degrees, similar to the present proposal. The number of counts versus M_{ee}^2 for 10 days of running with a beam current of about 3 nA is shown in Fig. 6b. The bins are evenly spaced in M_{ee}, with a width of 10 MeV. Fitting the data with an exponential slope, we find 0.006 counts expected in the region $9.5 < M_{ee}^2 < 9.7$, the sensitive region of this proposal. Scaling by the relative luminosity factor of about 200 between the EG1 data and this proposal, we predict about 1 background count, which is acceptable. The actual background rate will likely be lower, because phase space considerations likely will make the background fall faster than the exponential slope assumed.

Another check on the feasibility of detecting vector mesons through their decay to lepton pairs using an electron beam is provided by the same EG1 data set as mentioned above. As shown in Fig. 6a, the ρ, ω, and ϕ peaks are clearly seen above a smooth background, in spite of branching ratios to electron/positron pairs of only 4.5×10^{-5}, 7.0×10^{-5}, and 3×10^{-4} respectively.

The other source of background is wide-angle Bethe-Heitler pair production by high energy photons [17]. For a mass resolution of ± 6 MeV, this background is about two orders of magnitude below the J/ψ rate for exclusive photoproduction from free protons near threshold [5, 6]. Assuming that the Fermi-smearing effects are about the same for both processes,this ratio should persist for sub-threshold production from nuclei, as we verified explicitly using the formulas of [17] and the convolution model as for J/ψ photoproduction. The nuclear coherent BH production is strongly suppressed by the nuclear elastic form factor, just as the J/ψ nuclear coherent production is. This was checked with an explicit calculation using the formulas of Ref. [17]. Thus the background from wide-angle Bethe-Heitler leptons is expected to be negligible for this experiment.

6 Checkout

We will check out the muon counters before the run using cosmic rays. These will be used to adjust the electronics to obtain ADC signals in a useful range, and set the timing relative

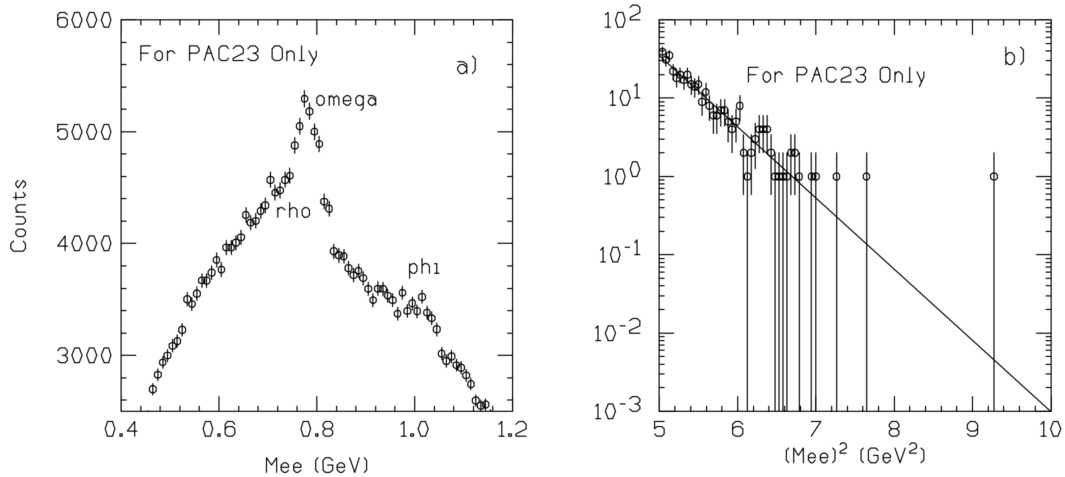

Figure 6: Very preliminary (for PAC 23 use only) electron/positron mass spectrum from EG1b in Hall B using 5.6 to 5.7 GeV electron beam on NH3/ND3 target. a) The mass region near the three common light vector mesons. The ω peak is clearly visible, while the ρ and ϕ peaks can also be seen above a smooth background. b) The high mass region, plotted versus mass squared. The line is a simple fit used for estimating backgrounds for this proposal.

to the lead glass blocks. With beam, we will use lepton coincidences from the various backgrounds discussed above to set the coincidence timing and check the spectrometer optics (i.e. the target pointing). To get a higher rate of coincidences, we will set the spectrometer momentum about 20% lower than nominal for this part of the checkout. If another similar experiment runs just before this one, it may be possible to do this checkout parasitically.

Table 1: Summary of beam, target, and spectrometer parameters.

Beam energy	6 GeV
Running time	7 days
Beam Current	60 μA
Target	3.4 cm Be (density 1.848)
SOS setting I (4 days)	1.78 GeV, 52.4°
SOS setting II (3 days)	1.78 GeV, 56°
HMS setting I (4 days)	3.60 GeV, 23°
HMS setting II (3 days)	2.82 GeV, 31.5°

7 Beam time and resource request

As shown in Table 1, we propose to measure sub-threshold J/ψ photoproduction from Be in a seven day run with the target and spectrometer conditions listed. We request a beam energy of 6 GeV. Once the spectrometers are set at the desired polarities, momenta and angles, no changes to the setup are expected during the run, except for the spectrometer angle/momentum change, which should only take a few hours. The only non-standard equipment needed are the muon counters and associated ADC and TDC channels, the thick Be target, and possibly additional shielding around the scattering chamber.

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